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BORDEAUX INJURY TO TOMATOES AND ITS EFFECT ON RIPENING

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ABSTRACT

THE factors responsible for the apparent paradox that 4–4–50 bordeaux mixture fails to increase yields of tomatoes commensurate with its ability to control leaf diseases have been under investigation both in the greenhouse and in the field by measuring the growth, blossoming, and fruiting of tomatoes sprayed with varying bordeaux mixtures, lime alone, and copper materials without lime.

The explanations commonly given for this paradox are (a) that bordeaux delays ripening or (b) that defoliation from disease accelerates it. Assuming that to redden a fruit is to ripen it, neither explanation seems valid. Bordeaux did not lengthen nor did artificial defoliation shorten the time from anthesis to ripening. Bordeaux, however, did dwarf the plants, kill meristems, deform young leaves and fruits, and cause defloration. These effects were reflected in a reduced final yield and this, in turn, caused the harvest curve to be flatter for sprayed than for nonsprayed plants. Bordeaux also hardened the leaves, accelerated transpiration, decreased growth cracks, caused fruits to russet occasionally, and increased the tendency of the pedicle to adhere to the fruit. It had little or no effect on blossom-end rot.

The leaf hardening seemed to be of two types, one presumably caused by the copper, the other by the calcium. Curtailed blossoming seemed to be related to dwarfing. Defloration probably resulted from (a) copper toxicity (b) accelerated transpiration, and (c) calcium hardening. Much of the damage of bordeaux to tomatoes, such as dwarfing, excessive transpiration, and defloration, seemed to be related either directly or indirectly to the alkalinity of the mixture. In some cases similar damage was caused by acid sprays, but not by neutral sprays.

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BORDEAUX INJURY TO TOMATOES AND ITS EFFECT ON RIPENING[1]

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INTRODUCTION

PLANT pathologists in New York State are confronted with the paradox that despite control of defoliation diseases of tomatoes by applications of 4–4–50 bordeaux mixture, the yield of fruit is reduced. The basic axiom is that healthy plants give higher yields than sick ones. In a disease year bordeaux-sprayed plants are patently more healthy than non-sprayed plants, but yet they yield considerably less.

It is both interesting and significant that farther south, where the season is longer than in New York State and where the diseases may be more serious, bordeaux applications may be followed by increased yields. In Louisiana, Edgerton (3)[3] reports a beneficial response to bordeaux in a disease year despite smaller harvests from the sprayed plants early in the season. He advances the theory that bordeaux mixture delays ripening, thus explaining these smaller harvests.

Poole (19) observed the baffling discrepancy between disease control and early yield and stated, "The fruit had prematurely ripened on the untreated plots".

Smith and Zimmerley (20) observed the same effect. They decreased defoliation by *Cladosporium fulvum* by increasing pressure at the spray nozzle, but could find no relation between the increased pressure and rate of ripening.

Geise, Zimmerley, and Spencer (6) added the significant finding that dusting gave higher yields than sprays on tomatoes, eggplants,

[1]The first two contributions in a series of papers on bordeaux injury appear in the *Journal of Agricultural Research*. (See literature citations, page 38.)

[2]The writers are grateful for assistance by Messrs. C. H. Cunningham, J. W. Heuberger, and R. N. Lindabury. This project has been conducted in cooperation with the Crop Protection Institute.

[3]Refers to Literature Cited, page 38.

cantaloupes, and cucumbers. They attributed reduction in early harvests on sprayed plats of tomatoes to accelerated ripening on non-sprayed defoliated plants, but in the case of cantaloupes where this theory had not gained ground, they were not so certain. They thought it might be "attributed at least in part" to defoliation by downy mildew.

Muncie (18) found it "a little surprising" that a bordeaux-soap mixture should give better control of Septoria leaf spot than plain bordeaux but at the same time give more ripe fruit. Here was a case of a large harvest despite better disease control. This probably was surprising because it did not fit the theory of delayed ripening.

Fromme (5) also found that soap bordeaux gave both better disease control and higher yields than plain bordeaux which gave fewer ripe fruits than even no spray.

It seems reasonably clear then that the spread between the harvest curves of bordeaux-sprayed and non-sprayed tomatoes cannot be explained, altogether at least, by accelerated ripening of blighted checks. This will be discussed in more detail later.

In 1929 a study of the problem of the so-called "delayed ripening" of bordeaux-sprayed tomatoes was undertaken at this Station. The study has continued every season since 1929, except in 1933. Thus data for 9 seasons are available. At various times since, the following factors in the complex have been isolated and scrutinized: Effect of sprays on growth and vegetative vigor of the plant, leaf deformation, blossom bud development, defloration, yield, growth of fruit, distortion of fruit, ripening, growth cracks, blossom-end rot, and transpiration. The effect of various factors in the spray mixture itself, such as the lime, the copper, the hydrogen ion concentration, and the effect of some of the new so-called "insoluble" copper compounds, have also been investigated.

While these experiments were in progress, other work on bordeaux transpiration (10) and injury to cucurbits (11) was going forward and is being published simultaneously.

MATERIALS AND METHODS

Most of the work on this problem has been done in the field, altho many points have been clarified in the greenhouse. A good strain of John Baer seed was used in the beginning, but it was further purified for research work by choosing seed from single desirable plants every year. Uniformity was increased for about four years, but not

much increase in uniformity was observed after the fourth year. The inbreeding reduced the average size of the fruit, however.

The field plats were single rows of from 50 to 70 plants duplicated in another part of the field. At picking time these rows were split into sections of 20 plants each. A 20-plant section was found to be sufficient for accuracy.

EFFECT OF NUMBER OF REPLICATE PLATS

In field research on a crop it is of some interest to know the minimum number of replicate plats necessary for significance. For the sake of record a curve showing the decrease in probable error of the mean with increase in number of replicate plats of 20 plants each is given in Fig. 1 for the 1930 data. It is clear that four or five replicate plats of 20 plants each constitute a sufficient number for accuracy. In all field work at least this number of replicate plats were used for picking records.

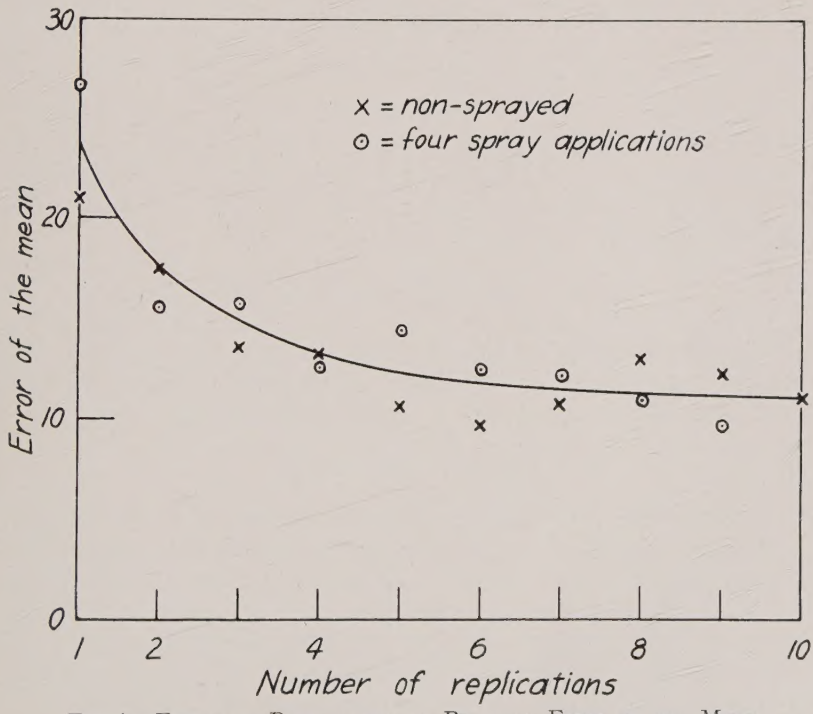

FIG. 1.—EFFECT OF REPLICATION ON PROBABLE ERROR OF THE MEAN FOR FIELD PLATS.

SPRAY MATERIALS

The basic spray included in all tests was 4–4–50 bordeaux, the standard recommendation in 1929 when the work was begun. The 4–4–50 formula refers to 4 pounds of copper sulfate pentahydrate and 4 pounds of hydrated lime in 50 gallons of water. To prepare it, snow grade copper sulfate was dissolved in the tank of water and hydrated lime was washed thru a screen while stirring. When low-lime bordeaux was desired the 4–2–50 formula was used. When other copper materials, such as red cuprous oxide or copper oxychloride were used in comparison, they were prepared to contain approximately equal quantities of metallic copper.

The pH of the completed sprays was as follows: Red cuprous oxide (Cuprocide), 6.7; copper oxychloride (Cupro K), 7.9; copper oxychloride (Compound A), 7.9; Cuprocide 54, 9.7; and bordeaux 4–4–50, 12.3. The pH of the 4–2–50 bordeaux in any application was uncertain as it varied with the carbonation of the lime used. At least one sample of lime used was one-third carbonated. This should have given a material with a pH approximating neutrality. The pH of 4–2–50 is 11.7 when pure ingredients are used (10).

The method of applying sprays varied somewhat. A hand sprayer was used in the greenhouse and in the field in 1929 to 1932, inclusive, and a power sprayer at 300 pounds pressure and a three-nozzle boom in 1934 to 1938, inclusive. Usually about 300 gallons of spray were applied per acre.

RESULTS

The experimental data are presented as far as possible under the general headings of: hyperplastic (enlarging) and hypoplastic (reducing) effects of the sprays on the tomato plant.

HYPERPLASTIC EFFECTS

Darker green color of foliage.—Bordeaux sprays make a tomato field look beautiful to the eye because they enhance the color of the foliage. There appear to be two causes for the darker green color of sprayed foliage, *viz.*, (a) optical illusion due to the blue of the bordeaux residue filtering some of the yellow from the green color of the foliage so that the green looks darker to the eye than it really is; and (b) to a stimulative effect on chlorophyll.

Several workers report that copper is either deficient in New York

soils or unavailable to plants. Mader and Blodgett (16) argue that bordeaux supplies copper to potatoes and increases their growth. Felix (4) and Knott (15) have shown that lettuce and onions, respectively, respond to copper in New York soils. Horsfall, Newhall, and Guterman (14) report that tomato and other seedlings sometimes grow more rapidly and show a deeper green color when the seeds are treated with copper compounds than when not treated. These reports may be taken as evidence that plants will respond to applications of copper in New York State.

Stimulation of adventitious buds.—Bordeaux-sprayed tomatoes, especially seedlings, sprout more readily from the lower part of the stem than non-sprayed plants. This is an indirect effect of the tendency to kill the growing point as mentioned below. This stimulation of adventitious buds causes bordeaux-sprayed plants to appear more bushy than normal plants.

Accelerated transpiration.—That bordeaux mixture increases transpiration of tomatoes at least under greenhouse conditions has been shown by many writers. It has also been observed at this Station. The occurrence of the phenomenon under field conditions seems to be inadequately proved, however. Miller (17), working in Kansas, failed to find any consistent effect of sprays on transpiration of tomatoes growing in the field. Certainly the condition of a tomato plant growing in the greenhouse where it is pampered is different from that of one growing in the field where living conditions are more rigorous.

The problem needs further research, but it can be considered that transpiration increases as pH of the spray mixture is shifted either way from neutrality. Neutral sprays like red cuprous oxide or copper oxychloride, do not increase transpiration. If the spray load is particularly heavy, stomatal plugging may be so extensive as to nullify some of the excess cuticular transpiration from bordeaux (10).

Wilson and Runnels (23) report that bordeaux mixture increases transpiration and increases blossom-end rot in the field while Volck oil reduces transpiration and reduces blossom-end rot. In only two years (1934 and 1938) has blossom-end rot been serious in any of the experimental plats. In 1934 both bordeaux mixture and red cuprous oxide sprays decreased blossom-end rot, so much so in fact, that the reduction was quite obvious to the eye (Table 1).

In 1936 there was a trace of blossom-end rot in the plats. During the season all tagged fruits from the defloration experiment were

harvested individually and graded for blossom-end rot. The disease was negligible on non-sprayed or on red cuprous oxide sprayed plants, but the plants sprayed with bordeaux yielded 4.3 per cent of blossom-end rot (Table 1).

TABLE 1.—EFFECT OF SPRAYS ON BLOSSOM-END ROT.

TREATMENT	BLOSSOM-END ROT, PER CENT			
	Aug. 14, 1934	Aug. 17, 1934	Aug. 22, 1934	Season of 1936
Non-sprayed	44.3	30.4	19.0	0.2
Bordeaux, 4–4–50	16.7	10.4	9.2	4.3
Red cuprous oxide, 1–50	27.6	11.1	9.6	0.0

In 1938 blossom-end rot appeared in a commercial field in Monroe County sprayed three times during August after the plants had attained their full growth. Excess transpiration caused by the bordeaux wilted the plants and caused some of the fruits to shrivel somewhat. On September 1, blossom-end rot counts were made on six 20-plant sections in adjoining rows of sprayed and non-sprayed plants. About 1,500 fruits were counted for each treatment. Blossom-end rot affected 43.5 per cent of the fruits on the bordeaux-sprayed plants and 53.4 per cent of the fruits on the non-sprayed plants. There appears to be a significant reduction in blossom-end rot because five out of the six 20-plant pairs showed fewer diseased fruits on the sprayed than on the non-sprayed rows.

In this experiment there was no question that bordeaux had increased the transpiration. The sprayed fruits were wrinkled. The spray did not increase blossom-end rot, however.

Increased fruit growth.—If bordeaux dwarfs the plants and leaves, as will be shown later, it might be expected to dwarf developing fruits also. Indeed, Dutton and Wells (2) have shown that bordeaux does dwarf cherry fruits. The locule walls of the tomato and the flesh of cherry fruits are both formed of parenchymatous tissue. Because of this similarity it might be expected that tomato fruits would also be dwarfed by bordeaux mixture. In every season, however, the average weight per tomato fruit was not less but greater for the bordeaux-sprayed plants than for the non-sprayed plants (Table 9, page 25). Since bordeaux-sprayed plants carried fewer fruits than the non-sprayed plants because of defloration, each fruit obviously would grow larger.

The difficulty, therefore, is to rule out the effect of defloration on fruit size. This was done in 1938 by spraying late in the season. In one commercial field in Monroe County three sprays were applied during August while a drought prevailed in the area. A picking was made on September 1 before enough time had elapsed for the effects of defloration to show. The ripe fruits were picked from four 20-plant randomized sections in each treatment. The average weight per fruit in pounds for plants treated with bordeaux and red cuprous oxide and for non-sprayed plants was 0.240, 0.288, and 0.277 pounds, respectively. Bordeaux reduced the size of these fruits when it was applied late enough in the season so as not to reduce the number. In fact the sprayed fruits were wrinkled, presumably because of the accelerated water loss and dry weather.

On the Station farm some plants were sprayed with bordeaux and red cuprous oxide thruout the season and some were sprayed after July 28. Normal rainfall prevailed during August in that area. The average weight of the fruits picked during August was determined (Table 2). It is clear that the fruits on the plants sprayed with bordeaux thruout the season were larger than on plants sprayed with bordeaux late in the season. The small size of the fruit on non-sprayed plants was due to defoliation from blight disease.

TABLE 2.—EFFECT OF TIME OF SPRAYING ON WEIGHT OF FRUITS.

TREATMENT	WHEN SPRAYED	AVERAGE NUMBER FRUITS PER PLANT	AVERAGE WEIGHT PER FRUIT, LBS.
Red cuprous oxide	Thruout season	12.3	0.257
Red cuprous oxide	After July 28	11.5	0.239
Bordeaux	Thruout season	8.7	0.255
Bordeaux	After July 28	10.8	0.234
Non-sprayed	———	12.1	0.225

It would appear that bordeaux reduces the fruit size of tomatoes as it does that of cherries, provided that defloration is not a factor. The reduction in size was not so great on the Station plats as in Monroe County, presumably because the soil was not as dry.

Another interesting observation was made on the effect of bordeaux on fruit growth in 1937. Bordeaux-sprayed fruits on certain harvest dates were misshapen (Fig. 2). There were few or no distorted fruits at the September 8 harvest (Table 3). The number of distorted fruits increased greatly by September 15 and fell off again by September 20. This fruit malformation seemed to be associated

FIG. 2.—TRACED SKETCHES OF DISTORTED TOMATO FRUITS GROWN ON BORDEAUX-SPRAYED PLANTS.

Left, two fruits from non-sprayed plants; right, four fruits from sprayed plants.

with rains. No rain fell for several days prior to September 8, but over one-half inch fell the day before the September 15 picking. Only a trace of rain fell between the September 15 and the September 20 picking.

TABLE 3.—EFFECT OF SPRAYS ON DISTORTION OF TOMATO FRUITS, 1937.

TREATMENT	SEPT. 15 HARVEST		SEPT. 20 HARVEST				SEASON HARVEST		
	Number of fruits per plant	Distorted fruits, per cent	Number of fruits per plant	Distorted fruits, per cent	Weight per fruit, lbs.		Average number of ripe fruits per plant	Average number of living leaves per plant	Average number of leaves per fruit
					Normal	Distorted			
Non-sprayed	4.78	25.1	4.08	12.5	0.269	0.109	35.3	312	8.84
Bordeaux, 4–4–50	4.35	71.2	6.86	61.5	0.276	0.342	19.6	404	20.61
Bordeaux, 4–2–50	5.03	41.2	6.26	24.9	0.245	0.328	32.8	448	13.66
Red cuprous oxide, 1–50	4.23	50.6	5.25	31.9	0.280	0.296	35.0	430	12.29

The symptom was also clearly associated with sprays, altho it occurred also on non-sprayed plants to some extent. There appeared to be a relation to the lime content of the sprays because high-lime bordeaux gave more distortion than low-lime bordeaux or red cuprous oxide. Lime, of course, cannot be the only factor involved as distortion occurred also on non-sprayed plants. Copper may play some part because plants sprayed with red cuprous oxide showed more distortion than non-sprayed plants. Another fair correlation is an inverse one between fruit distortion and number of fruits per plant.

In an effort to separate the effect of the spray on the parenchymatous tissue of the locule wall from the effect on the volume of the locule cavity, measurements were made of the length of the main axis of the fruit (stem to blossom end) for two harvests in 1938. Measurements of this main axis presumably would be more accurate than measurements of diameter. Because the fruit may have an uneven number of locules, no diameter measurement could be taken that would include only the locule wall. Displacement records to show volume were taken for the second harvest. All of these data are compared with average weight per fruit (Table 4).

TABLE 4.—EFFECT OF SPRAYS ON ENLARGEMENT OF TOMATO FRUIT.

SPRAY MATERIAL	WHEN APPLIED	AUG. 31 HARVEST				SEPT. 8 HARVEST			
				Average length, mm					
		Number of fruits per plant	Average weight per fruit, lbs.	Distorted fruits	Non-distorted fruits	Number of fruits per plant	Average weight per fruit, lbs.	Average length, mm	Average volume, cc
Bordeaux	Thruout season	3.90	0.285	46.94	46.93	——	——	——	——
Bordeaux	After July 28	——	——	——	——	5.86	0.246	47.80	110.40
Red cuprous oxide	Thruout season	4.52	0.276	48.85	——	5.72	0.250	49.32	——
Red cuprous oxide	After July 28	——	——	——	——	6.42	0.241	——	112.16

The main axis was shorter for fruits sprayed with bordeaux than for those sprayed with red cuprous oxide for both harvests whether the number of fruits per plant was reduced or not. No measurements

were made of fruits from the non-sprayed plants because they were suffering badly from defoliation.

In other words, the bordeaux curtailed enlargement of the parenchymatous tissue of the main axis of the fruit just as it does in the case of the parenchymatous tissue of the cherry fruit. Apparently, the larger weight of sprayed fruits which accompanies the reduction in number with defloration, is due to an increase in the size of the locule cavity, not in the length of the radial locule wall. This is further confirmed by the fact that the main axis of the fruits, distorted by bordeaux spray, was precisely the same as that of normal fruits.

The data on distortion of the fruits leads to the following tentative explanation: The malformation is primarily the result of an inrush of water into the fruits from rains. If this is so, the plants with the most fruits should show the least distortion (which is true) because there are more fruits to absorb the excess water. On the other hand, the plants with the most leaves should show the least distortion because the leaves should assist in removing the excess water from the plant. That this is not the case indicates that some other factor is involved. This other factor is spraying.

The distortion can only occur if the radial locule wall does not expand as rapidly as the cavity. In the case of the non-sprayed fruits, nothing disturbs this balance and there is little distortion. Bordeaux curtails expansion of the stem to blossom axis of the fruit (and presumably the locule walls as well), thus causing distortion.

To return to a comparison with cherries, bordeaux does seem to curtail expansion of the parenchymatous tissue of the tomato fruit as it does in the case of the cherry. This may occur despite a somewhat heavier fruit resulting from defloration.

Growth cracks.—On several occasions the opportunity was taken to measure the effect of sprays on cracking (Table 5). In general, it can be said that bordeaux mixture reduced cracking markedly and that red copper oxide reduced it somewhat.

If the cracking is due to an upsurge of water into the fruits, it should be reduced by any variation tending to offset this upsurge, such as (a) delaying the passage of water from the roots to the fruits, (b) increasing the ratio of leaf surface to number of fruits, (c) increasing transpiration.

Any explanation of the relation of sprays to these factors must take into account the fact that sprays acting as differently as red

TABLE 5.—EFFECT OF SPRAYS ON CRACKING OF FRUITS.

TREATMENT	PERCENTAGE OF CRACKED FRUIT AT DIFFERENT HARVESTS					
	Sept. 16, 1930	Aug. 22, 1934	Aug. 27, 1934	Aug. 10, 1936	Total tagging test, 1936	Aug. 25, 1937
Non-sprayed	84.2	43.3	54.5	64.9	45.0	83.4
Bordeaux 4–4–50	79.5	21.0	26.9	65.0	28.7	48.6
Bordeaux 4–2–50	——	——	——	——	——	74.3
Red cuprous oxide, 1 -50	——	36.0	56.8	64.8	33.0	65.5
Red cuprous oxide, 1–50 plus cottonseed oil, ½%	——	——	——	——	38.5	——
Cuprocide "54", 1¾–50	——	——	——	——	——	73.1
Copper oxychloride, 2½–50	——	——	——	——	——	70.9

copper oxide and bordeaux both reduce cracking altho the latter reduces it more than the former. Both materials tend to increase the ratio of leaf surface to number of fruits by defloration and by lessening the defoliation by disease control. Bordeaux is superior to red copper oxide for both purposes and would be expected, therefore, to reduce cracking more. Since red copper oxide has little accelerating effect on transpiration (10), the action of this material cannot be explained on that basis. Since bordeaux accelerates transpiration markedly, this fact can be used in explaining why bordeaux decreases growth cracking.

Whether sprays influence the permeability of tissues to water, has not been clarified. In the absence of data on this point it may be tentatively concluded that the reduction in growth cracks by sprays is due, in part at least, to an increase in leaf-fruit ratio and an increase in transpiration rate.

Russeting.—Apples are notoriously disposed to russeting from copper sprays. During eight seasons' experience no copper russet had been observed on tomatoes. During the ninth or 1938 season, however, a case came to light near Lake Ontario. Tomatoes sprayed once with Coposil by a grower on July 28 were rather badly russeted. Bordeaux in this instance did not russet the fruit. The symptoms can best be described by saying that they appear identical to those on the apple. The lesions varied from mere pin pricks to large corky areas 2 to 3 millimeters in diameter. This symptom is well illustrated in a report of the Wisconsin Experiment Station (Bulletin No. 440) published in 1938.

Increased pedicle adherence.—Most tomato fruits break off at a swelling on the pedicle, but some of them break off even with the fruit. Bordeaux seemed to increase the percentage of the stems adhering to the fruits in 1938. Two determinations were made comparing red copper oxide with bordeaux. Data were not taken from the non-sprayed plants because disease on the pedicles would affect the results. In the first case one worker picked carefully all the ripe fruit on the two plats (about 300 fruits per plat). In the second case all the green fruits on the plants were removed by shaking. Considering the ripe fruit on September 15, 78.4 per cent of the pedicles adhered on fruit sprayed with red copper oxide and 88.4 per cent on fruit sprayed with bordeaux. Considering the green fruit, the percentages were 61.1 and 75.6, respectively. This tendency of the stems to cling to the fruits sprayed with bordeaux may be similar to the tendency for the husks of bordeaux-sprayed pecans to stick to the nuts as reported by Demaree and Large (1).

HYPOPLASTIC EFFECTS

Hypoplasia characterizes most of the reactions of the tomato plant to bordeaux mixture. The leaves are hardened, the plant is dwarfed, the leaves and fruits are deformed, blossoming is curtailed, the plant suffers defloration, and the yield is reduced.

Hardening of the leaves.—On several occasions leaves of sprayed tomatoes were hardened. The same phenomenon has been observed on the leaves of roses, cucumbers, and hops. The affected leaves felt coarse and harsh to the touch and exhibited a woody type of texture. The symptom may have been most apparent on hot days.

In 1937 this harshness seemed to be slightly less apparent on plants sprayed with 4–2–50 than with 4–4–50 bordeaux, still less with Cupro K (which contains some calcium), and least with red cuprous oxide (which contains no calcium). These observations indicate that the harshness of the affected leaves may have been due to the hardening effects of the calcium in the spray (11).

In 1938, however, several "insoluble" copper compounds without lime (red cuprous oxide, copper oxychloride, copper zeolite, copper silicate, copper hydro 40, and basic copper sulfate) caused a stiffening and upcurling of tomato leaves. These leaves did not seem to be especially harsh. They felt rather as if they were more turgid than normal. This symptom was perhaps most noticeable at night. Frequently the edges of such leaves cracked under an effort to

straighten out the curl. Certainly this form of stiffening was not caused by lime but presumably by the copper. This type of stiffening appeared to be a distinct symptom type, but it may be a part of the harshness caused by bordeaux.

Dwarfing.—Bordeaux mixture, especially high-lime bordeaux, invariably dwarfed the tomato plant (Table 6). The dwarfing symptom was readily observed on seedlings (Fig. 3), altho it was apparent also on mature plants (Fig. 4) especially in the greenhouse where sprayed and non-sprayed plants could be grown close together for comparative purposes. The dwarfing was also observed in the field.

TABLE 6.—EFFECT OF COPPER SPRAYS ON GROWTH OF TOMATOES.

TREATMENT*	pH†	GREENHOUSE TESTS‡			AVERAGE GREEN WEIGHT (GRAMS) PER PLANT IN FIELD TESTS	
		Average green weight per plant, grams	Average dry weight per plant, grams	Average height, inches	Aug. 6, 1937§	July 14, 1938¶
Series I						
Non-sprayed	——	479.6	44.1	39.0	891.8	318.9
Bordeaux, 4–4–50	12.3	346.9	31.1	34.0	743.0	169.9
Bordeaux, 4–2–50	11.7	——	——	——	1,064.0	274.9
Red cuprous oxide	6.4	495.7	42.1	40.5	952.0	323.2
Red cuprous oxide plus cottonseed oil, ½%	6.4	532.2	45.7	40.2	650.0	——
Copper oxychloride (Cupro K)	7.9	——	——	——	870.0	339.8
Series II						
Non-sprayed	——	502.4	42.7	33.6	——	——
Hydrated lime, 4–50	12.3	377.6	31.1	32.6	——	——
Cuprocide "54"	9.7	556.2	45.7	36.6	——	——

*Copper content, 1 lb. metallic per 50 gals.
†Determined from laboratory samples.
‡Average of 10 plants for each treatment.
§Average of 5 plants for each treatment. These plants not well randomized, however.
¶Average of 12 plants for each treatment.

It was obvious that the lime in bordeaux was closely correlated with dwarfing (Table 6). A spray containing nothing but lime dwarfed the plants while sprays containing insolubilized copper without lime did not dwarf the plants and high-lime bordeaux produced more dwarfing than low-lime bordeaux.

Leaf deformation.—The leaf deformation aspect of sprays on tomatoes was observed first in the greenhouse in 1934 when it was found that acid clays (so-called inert diluents) and alkaline mate-

FIG. 3.—EFFECT OF SPRAYS ON GROWTH OF YOUNG TOMATO PLANTS IN THE GREENHOUSE.

Left to right, no spray, red cuprous oxide spray, bordeaux spray, no spray.

FIG. 4.—DWARFING EFFECT OF BORDEAUX ON OLD TOMATO PLANTS IN THE GREENHOUSE.

Left to right, no spray, red cuprous oxide spray, bordeaux spray.

rials, like lime and copper-lime dust (applied to wet leaves), deformed the leaves, but that neutral red cuprous oxide did not. The addition of red cuprous oxide to the acid clay seemed to enhance the

injury from the clay presumably because the acidity liberated soluble copper. The leaf deformation aspects of these materials are shown in Figs. 5 and 6. The spray seemed to kill the leaf at the margin. Continued growth of the rest of the leaf caused it to grow deformed.

FIG. 5.—DEFORMATION OF TOMATO LEAVES BY VARIOUS DUSTS APPLIED TO WET LEAVES.

Left to right, no treatment, red cuprous oxide alone, copper-lime dust.

A series of bordeaux mixtures were applied to groups of six tomato plants with a knapsack sprayer in the field in 1936. The sprays were as follows: Bordeaux formulas 4–1–50, 4–2–50, 4–4–50, lime alone, and red cuprous oxide alone. It was interesting to note that bordeaux 4–1–50 and 4–4–50 both produced much more leaf deformation than bordeaux 4–2–50. Lime alone also produced more

deformation than bordeaux 4–2–50, whereas red cuprous oxide alone produced no deformation. This tendency of bordeaux to deform leaves sometimes appears as a tendency to kill the growing points of the plant.

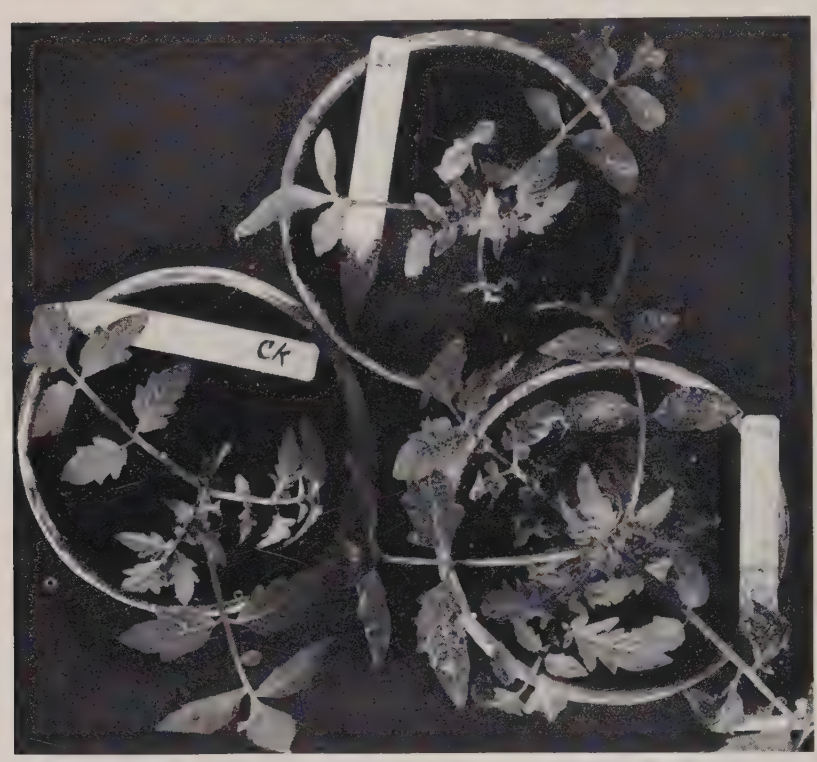

FIG. 6.—DEFORMATION OF TOMATO LEAVES BY VARIOUS DUSTS APPLIED TO WET LEAVES.

Left to right, no treatment, red cuprous oxide plus clay, red cuprous oxide plus lime.

The problem of bordeaux dwarfing and leaf deformation has already been considered (11) in some detail for cucurbits. It was shown that both symptoms were directly correlated with the pH of the spray mixture. Both increased as the pH shifted either way from a point approximating neutrality.

The data for tomatoes are not as complete as those for cucurbits, but they point to identical conclusions. As the pH of the spray

mixture increased above neutrality, the dwarfing increased (Table 6). The leaf deformation was more severe with an acid or an alkaline spray than with neutral sprays. In the case of the field test on the different bordeaux formulae, injury was more severe with the 4–1–50 formula (pH 4.4) and the 4–4–50 formula (pH 12.3) than with the 4–2–50 formula (pH near neutral).

It has been suggested elsewhere (11) that the possible causes of dwarfing and leaf deformation are (a) excessive transpiration, (b) hardening of cells by calcium absorbed internally, and (c) stomatal plugging with attendant reduced photosynthesis.

Fruit deformation.—The fruit deformation symptom of bordeaux injury should not be confused with the fruit distortion symptom, which has been discussed above. The fruit deformation symptom is similar to the leaf deformation, and appears to have the same cause. Bordeaux seems to kill a small area on a young fruit. Normal growth of the rest of the fruit makes it deformed. The dead area becomes corky and roughened as the fruit ripens. In this respect the symptom is similar to russeting. In the case of the distortion symptom, no killing is involved. This deformation symptom was not observed until the 1938 season. The plants sprayed with bordeaux 4–4–50 all season gave the following percentages of deformation for three successive harvests in August: 27.6, 40.0, and 10.6.

Reduced blossom-bud development.—It was observed in studying the effects of sprays on defloration, as discussed later, that fewer blossoms appeared on bordeaux-sprayed plants than on others. This fact results in a characteristic spread between the blossoming curves for sprayed and non-sprayed plants (Figs. 7 and 8).

In searching for an explanation, it was assumed that the spray did not retard blossom appearance *per se*, but that the effect was a result of the stunting action of the bordeaux. If so, there should be a straight-line relationship between dry weight and number of blossoms on plants irrespective of the spray.

A forcing variety of tomato (Forcing Wonder) was grown in the greenhouse and sprayed with various copper sprays in the spring of 1937 (Table 7). After the third group (truss) of blossoms had appeared, the plants were cut at the ground line, dried and weighed. The data indicate a rather clear-cut straight-line relationship between dry weight per plant and number of blossoms, irrespective of the type of spray applied (Fig. 9). A similar experiment was made in the field in 1937 using the pure line John Baer tomato (Table 7).

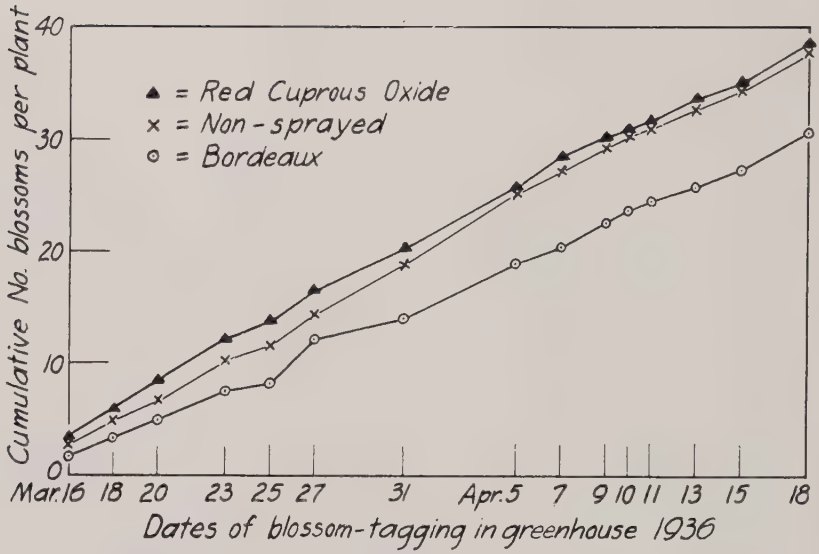
▲ = Red Cuprous Oxide
× = Non-sprayed
⊙ = Bordeaux
Cumulative No. blossoms per plant
0
10
20
30
40
Mar. 16 18 20 23 25 27 31 Apr. 5 7 9 10 11 13 15 18
Dates of blossom-tagging in greenhouse 1936

FIG. 7.—EFFECT OF BORDEAUX AND RED CUPROUS OXIDE ON BLOSSOMING OF TOMATOES IN THE GREENHOUSE.

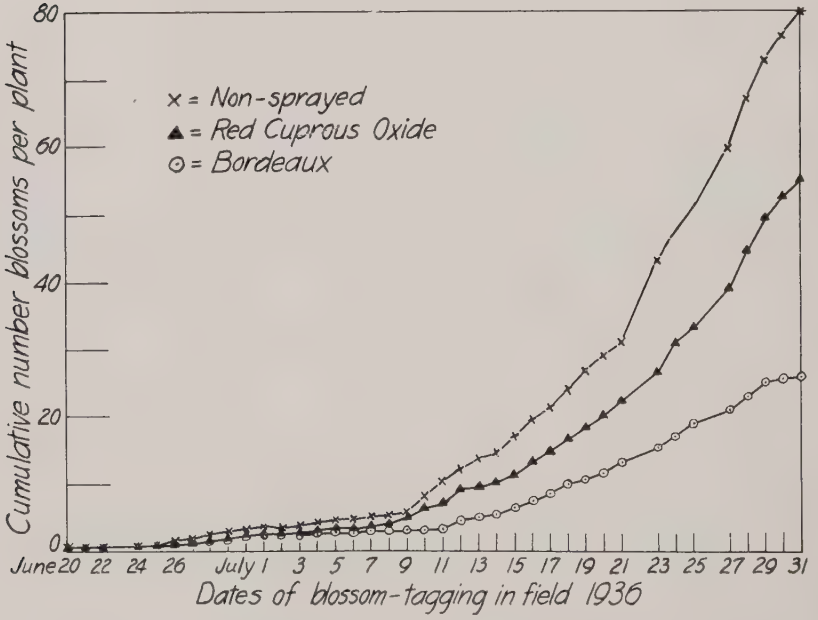
× = Non-sprayed
▲ = Red Cuprous Oxide
⊙ = Bordeaux
Cumulative number blossoms per plant
0
20
40
60
80
June 20 22 24 26 July 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Dates of blossom-tagging in field 1936

FIG. 8.—EFFECT OF BORDEAUX AND RED CUPROUS OXIDE ON BLOSSOMING OF TOMATO PLANTS GROWN IN THE FIELD IN 1936.

A curve plotted from these data also showed a similar straight-line relationship between number of blossoms and dry weight (Fig. 10).

TABLE 7.—RELATION BETWEEN DWARFING OF SPRAYED PLANTS AND BLOSSOM BUD DEVELOPMENT IN GREENHOUSE AND FIELD.

MATERIAL	AVERAGE PER PLANT		DRY WEIGHT PER BLOSSOM, GRAMS
	Dry weight, grams	Number of blossoms	
Series I. Greenhouse			
Non-sprayed	44.1	21.5	2.08
Bordeaux, 4–4–50	31.1	14.5	2.22
Red cuprous oxide, 1–50	42.1	20.0	2.16
Red cuprous oxide, 1–50, plus cotton-seed oil, ½%	45.6	20.6	2.24
Series II. Greenhouse			
Non-sprayed	42.7	17.0	2.51
Hydrated lime, 4–50	31.1	13.8	2.25
Red cuprous oxide, 1–50	45.7	18.6	2.45
Series III. Field, 1937			
Non-sprayed	116.3	106.6	1.09
Bordeaux, 4–4–50	99.5	103.0	0.96
Bordeaux, 4–2–50	141.9	151.4	0.94
Red cuprous oxide, 1–50	132.1	131.0	1.008
Red cuprous oxide, 1–50, plus cotton-seed oil, ½%	87.0	81.2	1.07
Red cuprous oxide, 1–50, plus pyrethrum, 4–50	89.2	83.4	1.07

In other words, the blossoming of the tomato appeared to be governed by the amount of dry substance in the plant, not by the spray as such. A similar explanation was found by Horsfall and Kertesz (12) to account for the apparent delay in blossoming of peas affected with root-rot and by Harrison (7) for a similar apparent delay in blossoming of beans due to mosaic.

Defloration.—Hedrick (8) pointed out 30 years ago that bordeaux was especially toxic to apple blossoms. This point was not given much consideration in vegetable spraying until very recently (13, 22). This aspect of bordeaux injury apparently accounts for a large share of the deleterious effects of the spray on yield of tomatoes and certain other vegetables.

Determinations of the magnitude of this effect were made in the greenhouse in 1936 and in the field in 1936, 1937, and 1938 (Table 8). In all cases pure line John Baer was used.

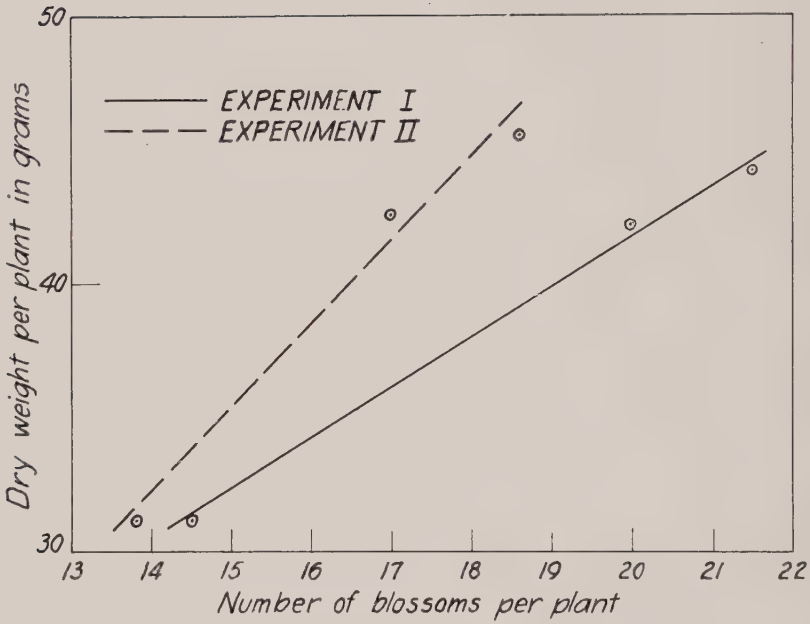

FIG. 9.—RELATION BETWEEN DRY WEIGHT AND NUMBER OF BLOSSOMS, GREENHOUSE EXPERIMENT, 1937.

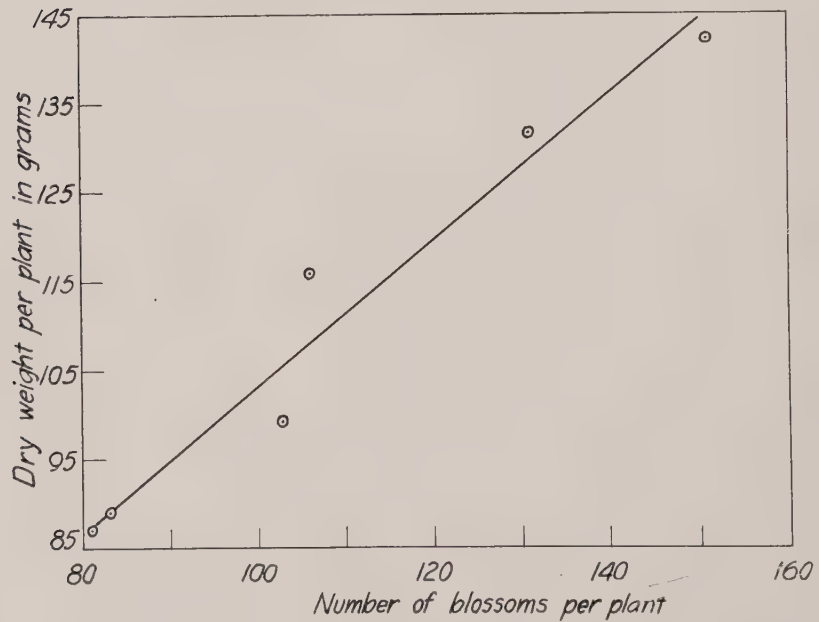

FIG. 10.—RELATION BETWEEN DRY WEIGHT AND NUMBER OF BLOSSOMS, FIELD EXPERIMENT, 1937.

TABLE 8.—EFFECT OF SPRAYS ON DEFLORATOIN OF TOMATOES.

TREATMENT	GREENHOUSE, 1936		FIELD					
			1936		1937		1938	
	Average number blooms per plant	Deflorated, per cent	Average number blooms per plant	Deflorated, per cent	Average number blooms per plant	Deflorated, per cent	Average number blooms per plant	Deflorated, per cent
Non-sprayed	42.3	1.2	80.6	22.9	106.6	7.7	458	4.1
Bordeaux, 4 4–50	39.1	14.8	25.8	48.4	103.0	17.5	90	27.8
Bordeaux, 4 2–50	—	—	—	—	151.4	20.8	351	11.4
Red cuprous oxide, 1 50	44.9	9.2	54.5	28.6	131.0	8.3	438	4.6
Red cuprous oxide, 1–50, plus cottonseed oil, ½%	42.7	4.7	70.4	25.9	81.2	3.2	—	—
Copper oxychloride (Cupro K)	—	—	—	—	100.2	10.0	492	4.5

Reduction of lime content of bordeaux mixture decreased defloration in 1938 but not in 1937. Sprays like copper oxychloride and red cuprous oxide, giving approximately neutral reaction in the spray tank, were less destructive to blossoms than an alkaline spray like bordeaux. Cottonseed oil reduced the defloration action of red cuprous oxide. The defloration effect was least in the greenhouse where growing conditions were least hazardous for the plant. In the field, defloration was more severe in 1936 when a serious drought prevailed than in 1937 when more moisture was available to the plants.

The explanation for defloration is not clear. There is evidence that excessive transpiration may be a factor because it is more severe under dry than under moist conditions and because bordeaux causes more defloration and more transpiration than red cuprous oxide or copper oxychloride. Transpiration cannot be wholly responsible, however, because red cuprous oxide causes little accelerated transpiration and yet it caused some defloration (10). It is probable that accelerated transpiration accounts for the difference between bordeaux and the neutral copper sprays, red cuprous oxide and copper oxychloride.

The effect of these no-lime copper sprays is probably due to copper injury on the pistil, on the pollen, or on both. The reducing effect of the cottonseed oil on red cuprous oxide injury fits this hypothesis since this material has already been shown to reduce copper injury from this material on foliage of roses, apples, and other copper-sensitive plants (9). In laboratory trials cottonseed oil has been found to reduce the fungicidal value of red cuprous oxide. If cottonseed oil, then, reduces the toxicity of red cuprous oxide to uncuticularized fungous spores, it should also reduce the toxicity to uncuticularized pistils and pollen grains. It seems probable, therefore, that bordeaux defloration is due to excessive transpiration and to copper injury.

Yield.—The reduction in growth, the reduction in number of blossom buds, and defloration caused by bordeaux mixture is reflected at picking time in reduced yields of tomatoes. Unless disease attacks early and heavily, the control of the disease by bordeaux has not seemed to compensate for the injurious effects of the spray on this crop (Table 9). In none of the seven years did bordeaux increase the yield over non-sprayed plants. Red copper oxide invariably gave higher yields than bordeaux, but only in 1934,

TABLE 9.—EFFECT OF SPRAYS ON YIELD OF TOMATOES IN THE FIELD DURING 6 YEARS.*

TREATMENT	1929		1930		1934		1935		1936		1937		1938	
	Number of fruits	Average weight lbs.	Number of fruits	Average weight lbs.	Number of fruits	Average weight lbs.	Number of fruits	Average weight lbs.	Number of fruits	Average weight lbs.	Number of fruits	Average weight lbs.	Number of fruits	Average weight lbs.
Non-sprayed	47.7	0.275	48.7	0.249	30.7	0.212	32.9	0.217	26.5	0.188	35.3	0.257	22.32	0.223
Red cuprous oxide	——	——	——	——	33.8	0.235	27.6	0.230	18.2	0.214	35.0	0.268	24.45	0.252
Bordeaux 4–4–50	42.3	0.283	48.1	0.269	28.7	0.221	26.9	0.238	7.8	0.217	19.6	0.317	17.84	0.256
Bordeaux 4–2–50	——	——	——	——	——	——	——	——	——	——	32.8	0.274	——	——

*Data expressed as average number of fruits per plant and average weight per fruit.

1937, and 1938 did plants sprayed with the copper oxide yield more than non-sprayed plants. Plants sprayed with red copper oxide yielded more than those sprayed with bordeaux, however, not because of better disease control, but because of less injury.

Ripening.[4]—Approximately 20 years ago Edgerton (3) observed the deleterious effects of bordeaux on tomato yields and advanced the theory that the mixture delayed ripening. What he observed was that the harvest curve of bordeaux sprayed tomatoes was not so steep as that of non-sprayed tomatoes. Edgerton could have called this delayed ripening of the sprayed plants or accelerated ripening of the non-sprayed plants, depending upon what base-line he used. It was probably neither. The theory of delayed ripening refers to the former, but the effect is commonly explained by the latter by saying that defoliation from leaf diseases on non-sprayed plants "causes a more rapid development of fruit". Typical cumulative harvest curves (Figs. 11, 12, and 13) for bordeaux-sprayed and non-sprayed tomatoes show that characteristic discrepancy. There is a spread between the harvest curves for sprayed and non-sprayed tomatoes. It is significant, however, that ripe fruits are picked as soon on the sprayed as on the non-sprayed plants.

The difficulty in assessing the harvest curves is that no adequate base line is available. The harvest curve for the non-sprayed plants may not be adequate because of defoliation. Likewise, that for the sprayed plants may not be adequate because of possible effects of the chemical. A method of canceling out the effect of defoliation is to plot curves for (a) field plats in years of defoliation (Fig. 11),

[4]The term "ripening" must be defined for the sake of clarity in the text. The New Standard Dictionary defines "to ripen" as "to grow to maturity". A ripe tomato is commonly thought of as a red tomato. If bordeaux affects the rate of ripening, it should, therefore, affect the rate of reddening or the time for the fruit to ripen. Misunderstanding can arise depending upon whether reference is made to ripening the individual fruits or to ripening the crop. In the case of dried crops like wheat the individual heads and the whole crop ripen essentially together, so that one may properly speak of the ripening of the whole crop. In the case of the tomato, however, the individual fruits ripen over a long period of time. In this case, "ripening" cannot be applied to the whole crop. The use of this term is reserved here for the individual fruit. In order to gather the whole crop of tomatoes several pickings are necessary. When the pickings are summed to obtain a curve, this is called a harvest curve—not a ripening curve. Technically, a ripening curve could not be plotted. There are no degrees of ripening under this definition. A fruit may be almost ripe, but it is unripe until it becomes red, and then it is ripe.

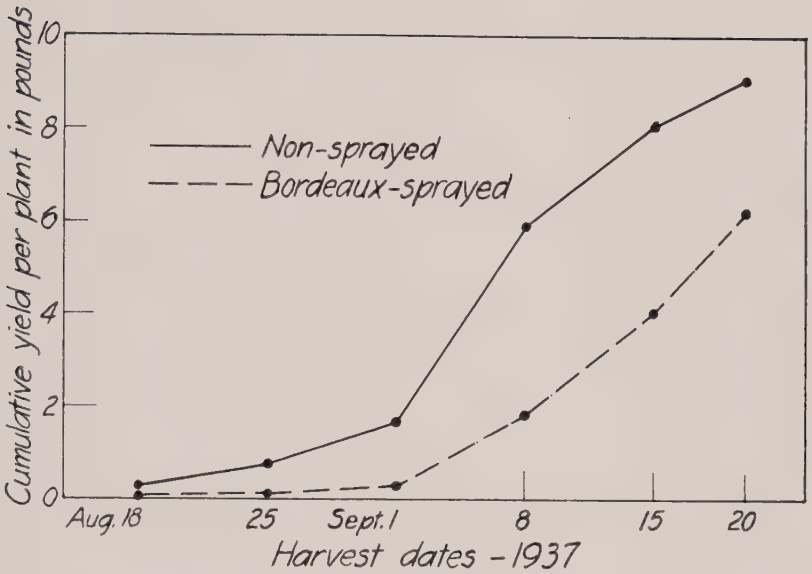

FIG. 11.—CUMULATIVE HARVEST CURVES OF BORDEAUX-SPRAYED AND NON-SPRAYED TOMATOES IN A DISEASE YEAR IN THE FIELD, 1937.

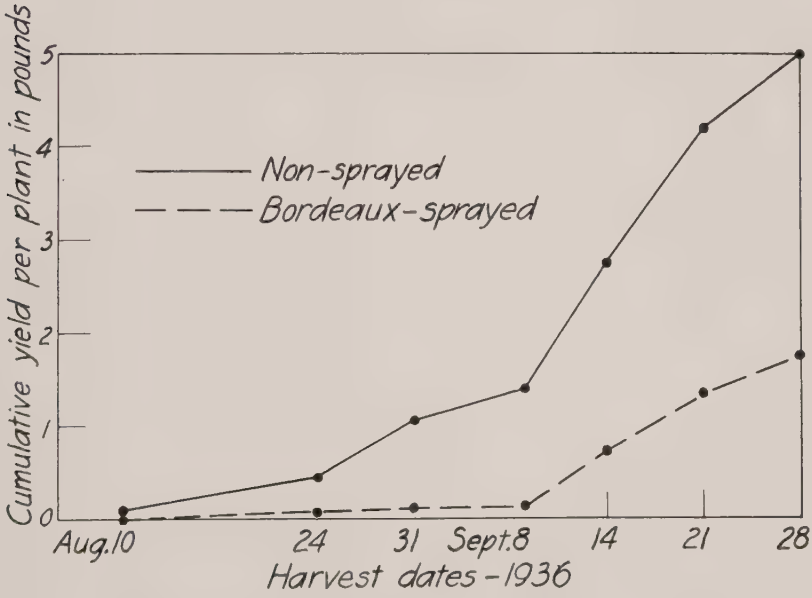

FIG. 12.—CUMULATIVE HARVEST CURVES OF BORDEAUX-SPRAYED AND NON-SPRAYED TOMATOES IN A YEAR OF NO DISEASE, FIELD, 1936.

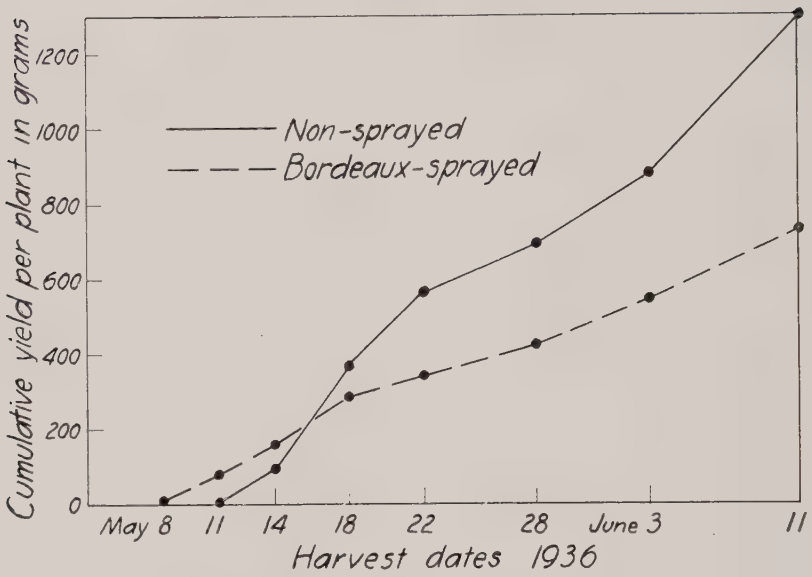

Fig. 13.—Cumulative Harvest Curves of Bordeaux-Sprayed and Non-Sprayed Tomatoes in the Greenhouse.

(b) field plats in years of no defoliation (Fig. 12), and (c) greenhouse tests under conditions of no disease (Fig. 13). In all cases the curves are similar, indicating that defoliation is not an important factor in shaping the early part of the harvest curve.

Another method of canceling out the effect of defoliation is to use artificial defoliation. Plants sprayed with red cuprous oxide were artificially defoliated in 1937 by picking off half of the leaves in mid-August. The leaves were kept picked off for the rest of the season. Harvest curves for these plants as compared with nearby undefoliated plants sprayed in the same manner show that the crop from defoliated plants was harvested no sooner than that from plants not defoliated (Fig. 14).

Watts (21) has shown lately that fruits from pruned tomatoes do not ripen faster than those from unpruned plants and that, altho some data purport to show that pruned tomatoes do ripen faster, these data really prove a larger number of early fruit per acre, not accelerated ripening.

It seems, then, that defoliation does not accelerate ripening, or if it does, the deleterious effects of the lost leaves compensate for it. Such being the case, the curve for the non-sprayed plants can be

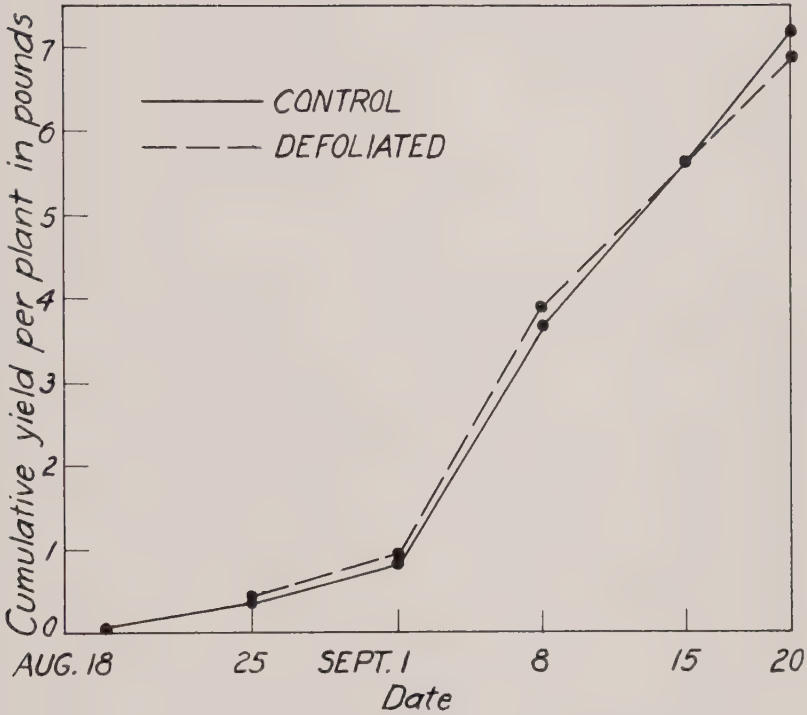

Fig. 14.—Cumulative Harvest Curve for Artificially Defoliated and Non-Defoliated Plants in the Field, 1937.

taken as the base line in assessing the two curves, at least in a no-disease year and in the early picking season of any year.

This is not to conclude, of course, that disease does not curtail yield. Once defoliation becomes serious, the plants set fewer fruits and add less carbohydrate to those already formed. This obviously affects yields and flattens the cumulative harvesting curve beginning about 6 weeks from the date of effective defoliation. This effect on shape of the curve occurs late in the picking season, however, not early, when any possible accelerating effect would show.

Since the cumulative harvest curves for the non-sprayed tomatoes can be taken safely as a base line in the forepart of the picking season, it is clear that the spread is due to a deleterious effect of the spray; not to a stimulating effect of defoliation.

Yield is governed by number as well as by weight of fruits. If the number of fruits picked is also plotted for the same experiments as

shown in Figs. 11 and 12, it is found that the curves are essentially the same (Figs. 15 and 16). It would seem then that the deleterious effect of sprays on yield is an effect on number of fruits, not on their speed of ripening.

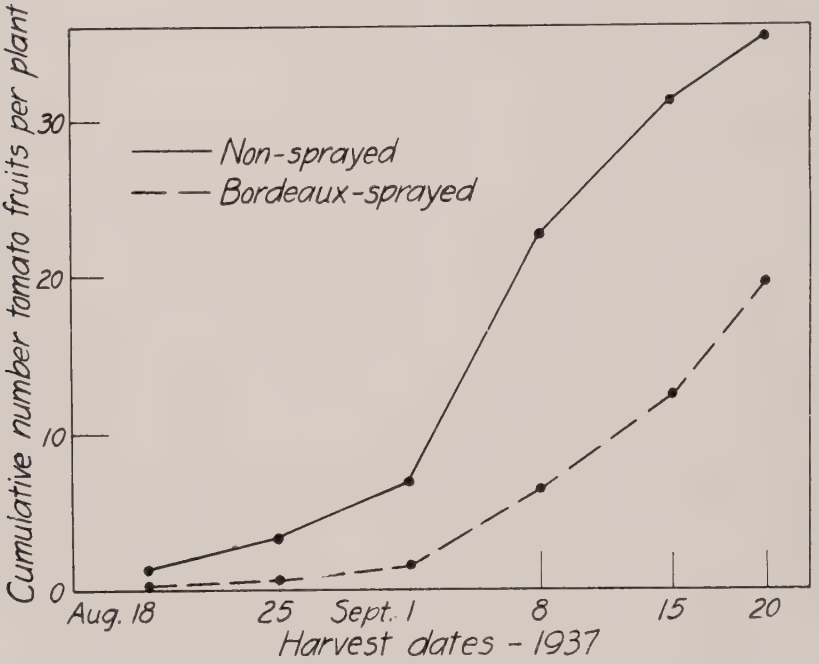

Fig. 15.—Cumulative Number of Fruits for Bordeaux-Sprayed and Non-Sprayed Tomatoes in a Disease Year, Field, 1937.

The various ways in which bordeaux can reduce the number of fruits have been discussed already. The information available on these factors may be summarized as follows: Since a plant forms flower buds in proportion to its size, the dwarfed bordeaux-sprayed plants will have fewer blossoms than non-sprayed plants. Bordeaux kills open blossoms, partly on account of the accelerated transpiration rate and partly on account of direct copper injury. These effects of the spray reduce the number of fruits which, in turn, reduces the yield and gives the apparent delay in the cumulative harvesting curve.

Finally, the possibility that bordeaux may lengthen the time from anthesis to ripening has been studied. Experiments in the greenhouse

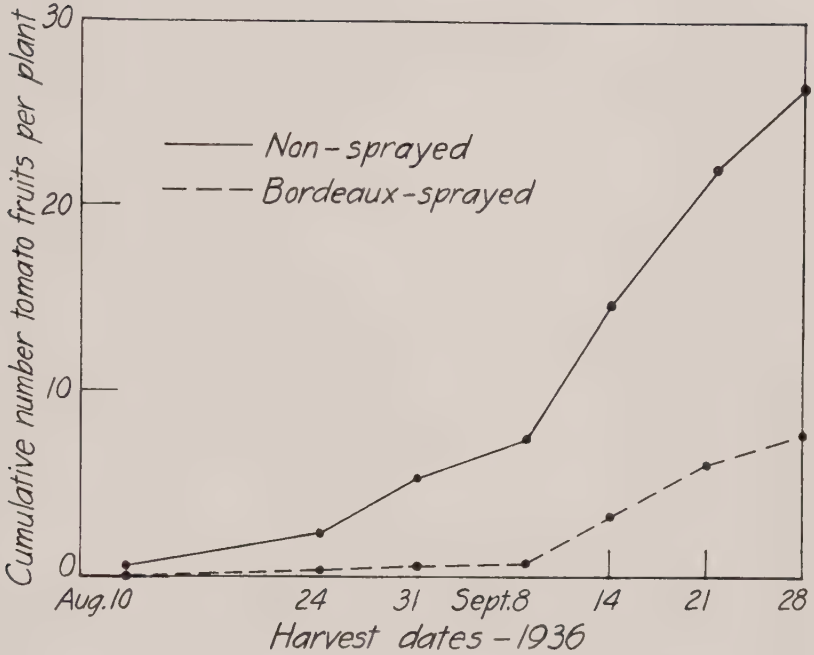

FIG. 16.—CUMULATIVE NUMBER OF FRUITS FOR BORDEAUX-SPRAYED AND NON-SPRAYED TOMATOES IN A YEAR OF NO DISEASE, FIELD, 1936.

with the plants growing under favorable conditions and in the field in 1936 under the other extreme of drought conditions show that the sprays have little or no effect whatsoever on the time for a flower to produce a ripe fruit (Table 10).

TABLE 10.—EFFECT OF SPRAYS ON TIME REQUIRED TO RIPEN TOMATO FRUITS.

TREATMENT	GREENHOUSE, 1936*		FIELD, 1936†	
	Number of fruits tagged	Number of days to ripen	Number of fruits tagged	Number of days to ripen
Non-sprayed	431	61.3	408	54.9
Red cuprous oxide, 1–50	347	61.8	260	54.6
Red cuprous oxide, 1–50, plus cottonseed oil, ½%	351	60.2	283	55.9
Bordeaux, 4–4–50	424	59.0	94	54.1

*Number of plants is variable up to 10.
†Data from 10 plants.

It may be reasonably concluded, therefore, that the spread in the cumulative harvest curves of bordeaux-sprayed and non-sprayed tomatoes is due to two factors, *viz.*, the spray dwarfs the plant so that it sets fewer blossoms, and it reduces the fruit-set. The operation of these factors, in turn, reduces the number of fruits picked on any one harvest date. Bordeaux, therefore, does not delay ripening. The grower might feel that bordeaux delays his harvest, but even that seems to be a fallacy. Bordeaux reduces his harvest.

DISCUSSION

An effort has been made during nine seasons to ascertain the reason for the failure of bordeaux mixture to increase yields of tomatoes commensurate with its ability to control leaf blights. Many factors have come to light. This bulletin makes no pretense at completeness in discussing the subject. Many angles of it are only inadequately understood.

Findings on the effect of bordeaux on the tomato plant are reported. The effects of bordeaux mixture on blight control are reserved for later publication. The chief approach has been to compare high- and low-lime bordeaux, lime alone, and various insolubilized copper compounds. This provided a series of materials with differing characters which afforded a means of studying how and why bordeaux injures tomatoes.

Bordeaux was not wholly injurious to the plant, however. It also produced certain hyperplastic effects. Sprayed foliage appeared much darker to the eye than non-sprayed foliage. Part of this darker green color appears to be due to an apparent stimulation of the chlorophyll. Many plants respond to copper nutrition in western New York.

A part of the dark green color appears to be an optical effect, however. The green in a leaf is composed, of course, of a yellow and a blue component. The blue bordeaux deposit filters out some of the yellow, permitting the blue component to pass thru so that the leaf appears to be darker than it really is. An apple leaf sprayed with bordeaux looks a darker green than one sprayed with lime-sulfur for the same reason.

The stimulation of adventitious buds is a hyperplastic symptom, but it results from a killing of growing points.

Accelerated transpiration of bordeaux-sprayed plants has been discussed elsewhere (10). The acceleration seems to result from an

increase in the permeability of the cuticle to water. Sometimes stomatal clogging may reduce water losses, especially in the middle of the day.

The effects of bordeaux on blossom-end rot are interesting. In only two years (1934, 1938) was the disease observed in much quantity on experimental areas. In both years bordeaux reduced the disease in what seems to be a significant fashion. In 1936, when the disease was mild, bordeaux seemed to increase it slightly. If blossom-end rot is a phenomenon purely of sudden excessive water removal, bordeaux should increase it and Wilson and Runnels (23) so report. Bordeaux increased water loss so much as to wilt the foliage rather badly in 1938 in a commercial field. The fruits were shriveled so that they looked wrinkled. It reduced the average weight from 0.277 to 0.240 pound each, showing also that water had been withdrawn. Still the sprayed plants produced fewer fruits affected with blossom end-rot than the non-sprayed plants in the next row.

The causation of blossom-end rot may not be quite as simple as postulated at present.

The effect of bordeaux on the growth of the fruits has afforded an interesting study. Bordeaux dwarfs cherries, but has invariably increased the average weight of tomatoes sprayed thru the season. It was found that bordeaux does dwarf the growth of the parenchymatous tissue of the locule walls homologous to the parenchymatous tissue of the cherry fruit. Since there are fewer fruits on sprayed than on non-sprayed plants, each one becomes larger.

Water passing into the fruit after a dry period swells it. Apparently, the locule walls can accommodate most of this on the non-sprayed fruits, but they are somewhat less flexible when sprayed with red copper oxide and very much less flexible when sprayed with bordeaux. As a result, fruits sprayed with red cuprous oxide become somewhat distorted as the locules expand. The bordeaux-sprayed fruits become still more distorted.

There appears to be an inverse correlation between stiffening of tissues of sprayed fruits and cracking; bordeaux-sprayed fruits are the stiffest and seem to crack least, red copper oxide-sprayed fruits are less stiff and crack somewhat more, while the non-sprayed fruits are least stiff and crack most.

Presumably, the resistance to swelling and then to cracking is due in the one case to the slight stiffening action of the copper, and in the other, to the added stiffening effect of the calcium.

Altho bordeaux does produce some hyperplastic symptoms, the usual plant response is hypoplasia. The dwarfing reaction to ordinary bordeaux is chiefly a response to the lime and not to the copper. The causes of the dwarfing of tomatoes appear to be the same as those for dwarfing of cucumbers (11). The lime probably functioned to accelerate transpiration (10) by saponifying the cuticle and by penetrating thru the cuticle to harden growing tissues and keep them from expanding as much as normal. Sprays also clogged stomata, thus curtailing photosynthesis with attendant dwarfing. Leaf and young fruit deformation seem to have much the same explanation as the dwarfing.

There appeared to be two symptom types of leaf hardening difficult to distinguish in writing. In one case the leaves seemed to be extra turgid as if they were gorged with water. They curled upward at the edges as if the spongy tissue below was more turgid than the palisade layer above. This symptom was perhaps somewhat more noticeable at night than in the daytime and possibly more noticeable on young than on old plants. An effort to smooth out the curl cracked the lamina. This was probably a copper symptom as all copper compounds produced it.

The other type of hardening was a certain harshness akin to woodiness. There was no upcurling and little tendency for the leaves to break. It was perhaps most noticeable on hot days. This type seems to be due to the calcium in the spray as it decreased with decreasing calcium content and was absent with no-lime sprays.

The blossoming of plants treated in different ways is an interesting study. Reductions in blossoming for pea plants affected with root-rot, bean plants affected with mosaic, and tomato plants sprayed with bordeaux have all been studied at this Station (12, 7, 13). In all cases this reduction has been found to be a function of the size of the plant. When anything reduces the plant size, it reduces the ability of the plant to form blossom buds and this is reflected in the blossoming curve. It is interesting that this should be the case whether the deleterious factor be root-rot, mosaic, or spray damage.

Hedrick (8) observed 30 years ago that bordeaux was toxic to apple blossoms, but it was nearly a quarter of a century before the problem received attention on vegetables (22, 13). The problem is more important in vegetable than in fruit pathology. Fruits blossom within a relatively short period, while vegetables bloom all summer. Fungicides applied to almost any vegetable will strike open blossoms.

Defloration appears to have several causes. The acceleration of transpiration by bordeaux or other high pH sprays seemed to increase defloration since it was aggravated by dry weather. Direct copper injury to the pistil may also increase defloration. There remains another possibility, perhaps somewhat tenuous as yet, that calcium from bordeaux may harden the pistil so that fertilization is curtailed.

The deleterious effects of bordeaux on growth, blossoming, and fruit-set were reflected in smaller harvests. If any treatment is destined to reduce the final yield of a crop harvested in series, the cumulative harvesting curve obviously will never be so steep for the treated as for the non-treated. This fact has given rise to what seems to be an erroneous theory that spraying delays ripening.

Ripening may be defined essentially as the reddening of the individual fruit. If a crop, like wheat for example, matures practically all heads simultaneously, the crop may be said to ripen. But if several pickings are necessary in order to gather the whole crop at a ripe stage, the crop cannot be said to ripen; only the individual fruits ripen. A curve representing the rate of gathering the crop is a harvest curve — a picking curve, not a ripening curve.

It is significant that ripe fruits have always appeared as soon on the bordeaux-sprayed as on non-sprayed plants. The length of time between transplanting and the first ripe fruit, therefore, has not been altered by the spray. Moreover, experiments with tagged blossoms in both the greenhouse and in the field show that the time from anthesis to reddening was not changed by spraying. It is clear, therefore, that bordeaux mixture does not delay ripening.

The effect of bordeaux on growth and defloration may so reduce the number of fruits per acre that the first picking is postponed until a sufficient number of ripe fruits are present. This is a question of postponed harvest which must not be confused with delayed ripening.

There remains the possibility that defoliation diseases may accelerate ripening. Since no blight occurred during the year when extensive tagging operations were underway, no direct data on this point are available. In 1937, however, artificially defoliated plants ripened no faster than similar plants not defoliated. Watts (21) concludes that defoliation by pruning does not accelerate ripening of tomatoes and Woods (24) states that reddening of the individual fruits is not affected by pruning. It seems reasonably clear that defoliation will not accelerate ripening.

How then explain the general feeling that blight diseases do accelerate ripening? The observations commonly cited in support of these conclusions are that late in the season blighted plants show many more ripe fruits than non-blighted plants and that the frost catches many more green fruits on sprayed than on non-sprayed plants.

The red fruits can be seen much more readily, of course, on the blighted than on the non-blighted plants because there are no leaves to hide them. This is a striking optical effect in fields containing both blighted and non-blighted plants, but this does not answer the point about frost.

The tomato is an indeterminate grower. It will continue to produce fruits as long as conditions are favorable. Other things being equal, therefore, all the tomato plants should show many green fruits at frost time. The sprayed plants do. They are, therefore, normal in this respect. Blighted plants do not; they are abnormal. The blight has made them abnormal in this respect because it has killed the leaves and crippled the stems that would have produced the flowers that would normally have produced the green fruits for the frost to kill.

The high percentage of frosted fruits on non-blighted plants proves only that the plants were still producing; it is no proof that spraying delayed their reddening, or that blight accelerated the reddening of non-sprayed plants.

SUMMARY

1. A study has been made of the failure of bordeaux to give increased yields of tomatoes commensurate with disease control.

2. The problem has been attacked by comparing the effects of a series of spray materials simulating somewhat the components of bordeaux mixture. The sprays were low-lime and high-lime bordeaux, lime alone, and insolubilized copper compounds without lime. Tests were conducted in the greenhouse and field during nine seasons beginning in 1929.

3. Bordeaux produced two general symptom types, hyperplasia and hypoplasia. The hyperplastic symptoms were darker green foliage, stimulation of adventitious buds, accelerated transpiration, increased fruit size, decreased growth cracks, russeting, and increased pedicle adherence. The hypoplastic symptoms were hardening of

leaves, dwarfing, leaf and fruit deformation, reduced blossom-bud development, defloration, and reduced yield.

4. The darker green color of the bordeaux-sprayed foliage was due to an optical effect and copper stimulation.

5. Adventitious buds were stimulated by the killing of meristems.

6. Bordeaux accelerated transpiration sometimes sufficiently to shrink the fruits, but it did not increase blossom-end rot.

7. Bordeaux increased fruit growth because there were fewer fruits on sprayed than on non-sprayed plants.

8. Bordeaux reduced enlargement of the parenchymatous cells of the locule wall in the same way that it dwarfs cherry fruits.

9. Bordeaux reduced growth cracking.

10. Copper compounds sometimes russeted the fruit to give a symptom similar to russet on apple fruits.

11. Bordeaux seemed to increase the tendency of the pedicle to adhere to the fruit when picked.

12. Bordeaux hardened leaf tissues. The hardening was of two types, turgidity which was due apparently to copper and a woodiness which was due apparently to calcium.

13. The dwarfing symptom of bordeaux injury probably resulted from three factors, *viz.*, accelerated transpiration, plugging of stomata with attendant reduction in photosynthesis, and hardening by the lime so that cell expansion was curtailed.

14. Bordeaux killed growing points and deformed leaves and fruits.

15. Reduced blossom-bud development was a function of dwarfing; the smaller the plant the fewer the blossoms.

16. Defloration appeared to result from the action of several factors including direct copper toxicity, accelerated transpiration, and calcium hardening.

17. Reduced yield resulted from reduced blossom-bud development and defloration.

18. Neither bordeaux itself nor artificial defoliation affected the rate of ripening.

19. In disease years, frost killed more green fruits on sprayed than on non-sprayed plants because the disease prevented the continued setting of fruit on non-sprayed plants.

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